# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2428

AN INVESTIGATION OF AIRCRAFT HEATERS

XXXVI - PRELIMINARY INVESTIGATION OF A

COMBUSTION-TYPE AIRCRAFT HEATER

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Washington
August 1951

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## SUMMARY

Experimental results on the thermal performance of an aircraft combustion-type heater are presented. The heater is rated at 50,000 Btu per hour and is a type used for cabin heating and anti-icing systems. The performance of this combustion-type heater with a counterflow and a parallel-flow return passage on the gas side does not appear predictable by use of existing equations for the following reasons: (1) The mechanism of heat transfer for swirling gases inside the combustion chamber is not accurately known; and (2) accurate mixed-mean temperature measurements of the burning fuel inside the combustion chamber were difficult to obtain.

The thermal conductance for the gases within the combustion chamber is predicted to be many times lower, by use of existing equations, than the experimental data indicate.

To compare the relative effects of gaseous radiation and turbulence due to the process of combustion with that of forced convection alone in the absence of combustion, preheated-gas runs were made as well as "combustion" runs. Evaluation of the thermal effectiveness of the heater for these two types of tests reveals that the effects of gaseous radiation and turbulence due to the process of combustion are negligible.

## INTRODUCTION

The combustion-type aircraft heater was tested in the Mechanical Engineering Laboratories of the University of California. This heater is designed to be used for cabin heating and wing- and tail-surface anti-icing systems.

At the present time, methods of thermal analysis for this type of combustion heater have failed to yield results which compare with measured values. Two reasons for this failure are

1. Inadequate knowledge of the mechanism of heat transfer from the burning, swirling gases inside the combustion chamber to the chamber walls; that is: (a) The unit thermal conductance for a jet of inert fluid passing along the inside of a cylinder in a spiral path is not known; (b) eddies and turbulence caused by combustion of fuel probably increase the effective thermal conductance over that for unburned gases; and (c) radiation from solid or gaseous constituents of the gases to the combustion chamber walls may yield added heat-transfer rates

2. Difficulty in specifying the mixed-mean temperature of the combustion gases in the combustion chamber to be used in the prediction equations

The total effect of items 1(b), 1(c), and 2 was determined by the following procedure: After the tests utilizing a gasoline and air mixture (referred to as "combustion" tests) were completed, further tests were made with hot (but not burning) gases passing through the combustion chamber (referred to as "preheated-gas tests"). The latter tests were thus made in the absence of turbulence due to combustion (item 1(b)), solid and gaseous radiation (item 1(c)), and difficulty in measuring hot-air temperature in the combustion chamber (item 2). A comparison of the preheated-air tests with combustion tests therefore reveals the total effect of these three items.

The results reveal (fig. 1) that the heat-transfer rates for the combustion tests were greater than those for the preheated-gas tests only by the ratio of the respective inlet-temperature differences. Thus, the effects of items 1(b), 1(c), and 2 can be said to be negligible.

The following measurements were made:

1. Weight rates of combustion gas, preheated air, and ventilating air

2. Weight rate of fuel (gasoline) to heater (for combustion tests)

3. Inlet and outlet temperatures of combustion gas, preheated gas, and ventilating air

This investigation, part of a research program investigating aircraft heat exchangers at the University of California, was conducted under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

## SYMBOLS

| | |
|---|---|
| $c_{p_a}$ | heat capacity, at constant pressure, of air, Btu/(lb)(°F) |
| $c_{p_g}$ | heat capacity, at constant pressure, of gas, Btu/(lb)(°F) |
| $q_a$ | heat transferred to ventilating air, Btu/(hr) |
| $W_a$ | weight rate of ventilating air, (lb)/(hr) |
| $W_c$ | weight rate of combustion air, (lb)/(hr) |
| $W_f$ | weight rate of fuel, (lb)/(hr) |
| $W_g$ | weight rate of combustion gases, (lb)/(hr), $(W_c + W_f)$ |
| $\tau_{a_{in}}$ | temperature of inlet ventilating air, °F |
| $\tau_{a_{out}}$ | temperature of outlet ventilating air, °F |
| $\tau_{g_{in}}$ | temperature of entering preheated air, °F |

## DESCRIPTION OF HEATER AND TESTING PROCEDURES

The 50,000-Btu-per-hour combustion-type heater with parallel and counterflow passages is shown in figure 2. The heater is cylindrical in form, 18 inches long and 7 inches in diameter.

Combustion takes place inside a cylindrical combustion chamber which lies within two concentric cylinders. The combustion chamber and passages are constructed of heat-resisting alloy steel and are fully welded. The fuel and air inlets and exhaust-gas outlet are placed near the upstream end of the heater. Four cross-over passages connecting the combustion chamber to the return passage are placed at the downstream end of the heater.

A removable head, which holds a vaporizing wick with a glow-coil igniter mounted at its center, covers the upstream end of the combustion chamber. Fuel is fed to the wick and is vaporized inside the chamber. A stainless-steel jacket surrounds the combustion chamber and return passage. A diagram of the heater test stand is given in figure 3. Air enters tangentially into the combustion chamber just downstream from the wick, thereby inducing added turbulence to allow vaporization of the fuel.

All regulating devices were removed from the heater for these tests.

A $1\frac{1}{2}$-inch bellmouth orifice was used to meter the ventilating air and a 5/8-inch bellmouth orifice was used to meter the combustion air. Measurement of fuel rates was made with a calibrated rotameter.

The inlet temperatures of the combustion air and ventilating air were measured by means of thermocouples. Outlet temperatures were also measured by means of traversing thermocouples (see fig. 3).

Preheated gas was introduced into the heater as shown in figure 3. Temperature measurements of the entering preheated gas were made by means of a shielded thermocouple.

## HEAT-TRANSFER RESULTS

The results of the combustion tests are given in figures 4 and 5. These results are for runs of three air-fuel ratios of 26, 20, and 16, with three fuel rates 2.5, 3.0, and 3.5 pounds per hour. The ventilating air weight rates ranged from 600 to 1400 pounds per hour.

The curve representing the highest fuel weight $W_f$ shows the greatest heat-transfer rate (fig. 4). This fact can be explained as follows: Theoretically, the temperature of the combustion mixture is only a function of the air-fuel ratio. Then, at a constant ventilating-air weight rate and constant air-fuel ratio, the heat transferred will increase with fuel weight rate because of the increased unit thermal conductance along the combustion-chamber walls (due to greater weight rate of gases). Also a greater over-all temperature difference will be obtained between the combustion gas and the ventilating air because of the small temperature decrease of the combustion gases.

The theoretical air-fuel ratio for complete combustion yielding approximately the greatest adiabatic temperature is 15.3, by weight, based on the following equation (references 1 and 2):

$$2C_8H_{18} + 25\ O_2 \rightarrow 18H_2O + 16CO_2$$

All runs were made at air-fuel ratios greater than the theoretical because the heater would not operate satisfactorily at lower air-fuel ratios.

The lowest air-fuel ratio yields the greatest heat-transfer rate at a constant fuel rate and ventilating-air rate (fig. 5). This could be the result of at least two phenomena:

1. The lowering of the adiabatic temperature due to dilution by the excess combustion air overcomes the increase in unit thermal conductance and the small temperature decrease in the combustion gases mentioned above.

2. Should there be poor mixing of air and fuel within the combustion chamber, even at ratios greater than the theoretically correct air-fuel ratio, there might be regions of rich mixtures allowing local incomplete combustion and radiation from the formation of luminous particles of carbon. The existence of these regions would tend to increase the effective thermal conductance along the inside of the combustion chamber and allow greater heat transfer.

In order to determine the presence of heat transfer due to radiation from luminous carbon particles and also the fraction due to induced turbulence caused by the combustion mechanism, hot, nonluminous, preburned gases at about 1600° F were drawn through the heater in place of the combustion process within the combustion chamber. The results of this test were plotted in figure 1 together with the results of the combustion runs. It should be noted that the ordinate of the curve $\dfrac{\tau_{a_{out}} - \tau_{a_{in}}}{\tau_{g_{in}} - \tau_{a_{in}}}$ is the heater effectiveness, which is the fraction of the maximum possible amount of heat that could be transferred to the air. Because the points of both sets of runs tend to fall on the same curve, the effectiveness of the heater is then the same for the combustion and preheated-gas runs. This result would tend to indicate that the luminous radiation of hot carbon particles and induced combustion turbulence (both factors being such as to increase the heater effectiveness) play a negligible role in accomplishing heat transfer in this heater.

Heat-balance agreements are, on the average, within 15 percent for both the combustion and preheated-gas tests.

## CONCLUSIONS

From an experimental investigation of an aircraft combustion-type heater, the following conclusions were drawn:

1. The effect of added heat transfer from the combustion gases due to radiation from the solid or gaseous constituents of the gases to the combustion chamber walls is negligible.

2. The effect of added heat transfer from the combustion gases due to the increase in the effective thermal conductance within the combustion chamber caused by eddies and turbulence induced by the combustion of fuel is negligible.

3. Further analysis and experimentation are required for the study of the mechanism of heat transfer and combustion inside the combustion chamber in order to predict more accurately the thermal behavior of this heater.

Department of Engineering,
University of California,
Berkeley, Calif., February 26, 1946

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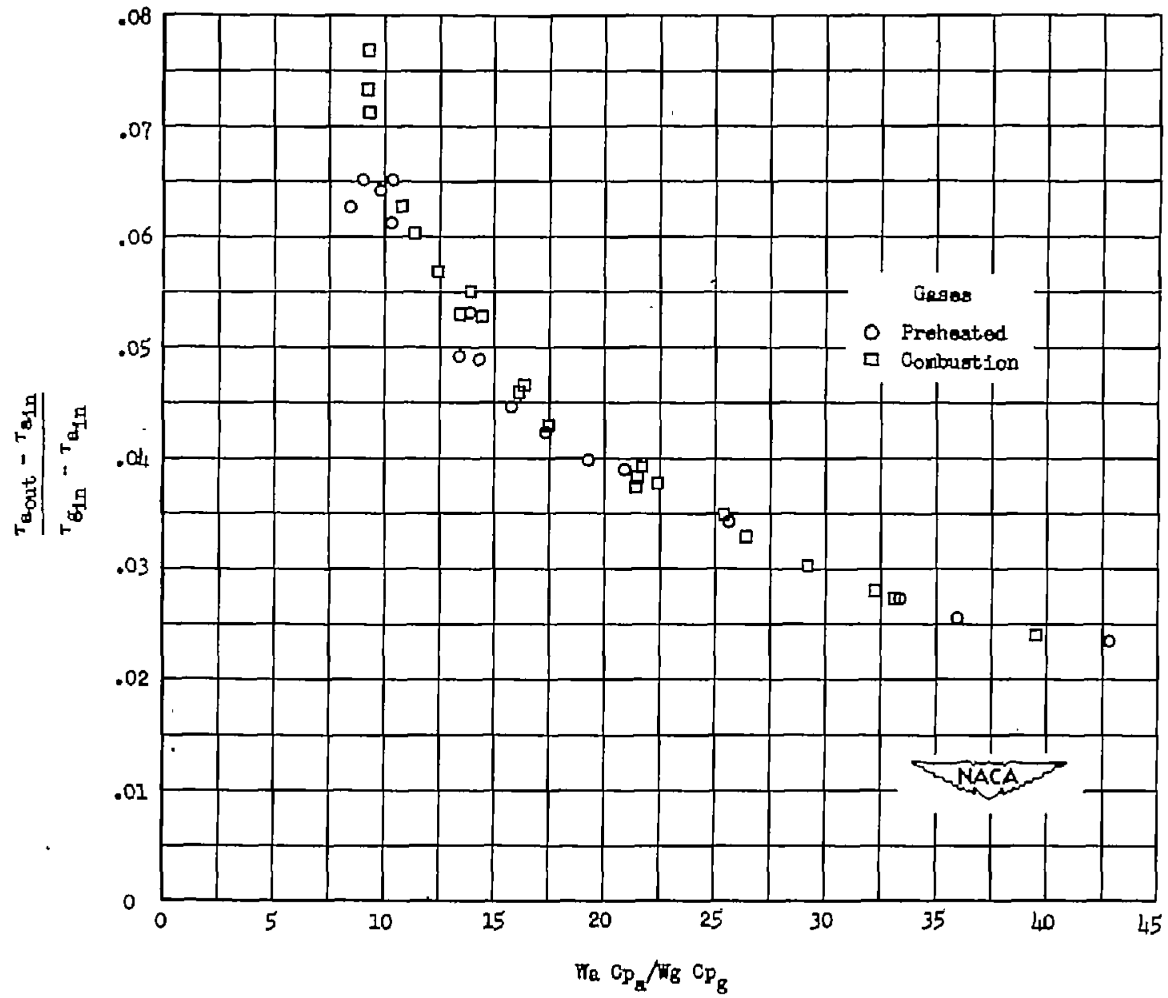



Figure 1.- Comparison of combustion and preheated-gas tests.

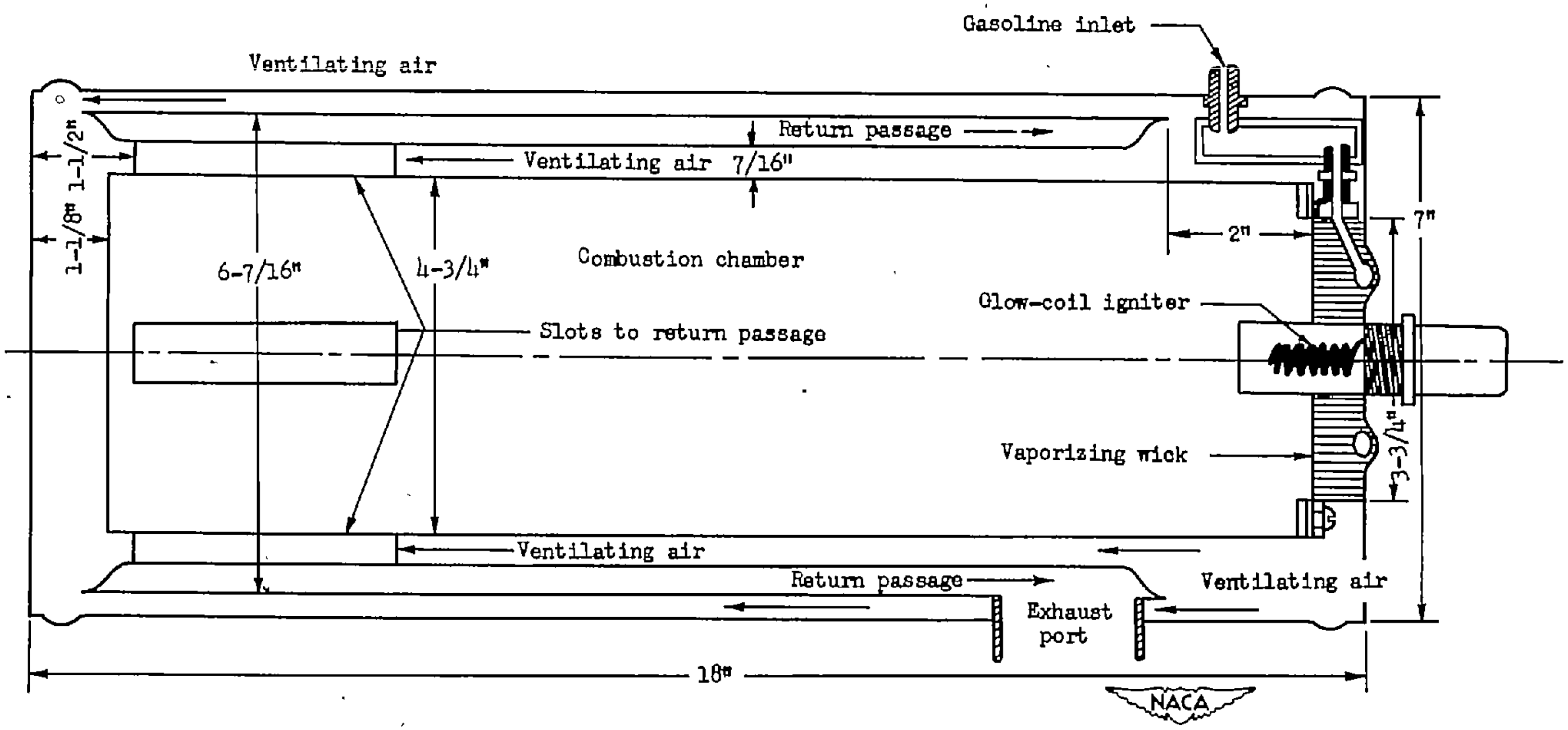



Figure 2.- Gasoline-fired aircraft combustion heater. Air-side cross-sectional area, 0.087 square foot; gas-side combustion-chamber cross-sectional area, 0.123 foot; gas-side return-passage cross-sectional area, 0.057 square foot. Scale, 1/2 size.

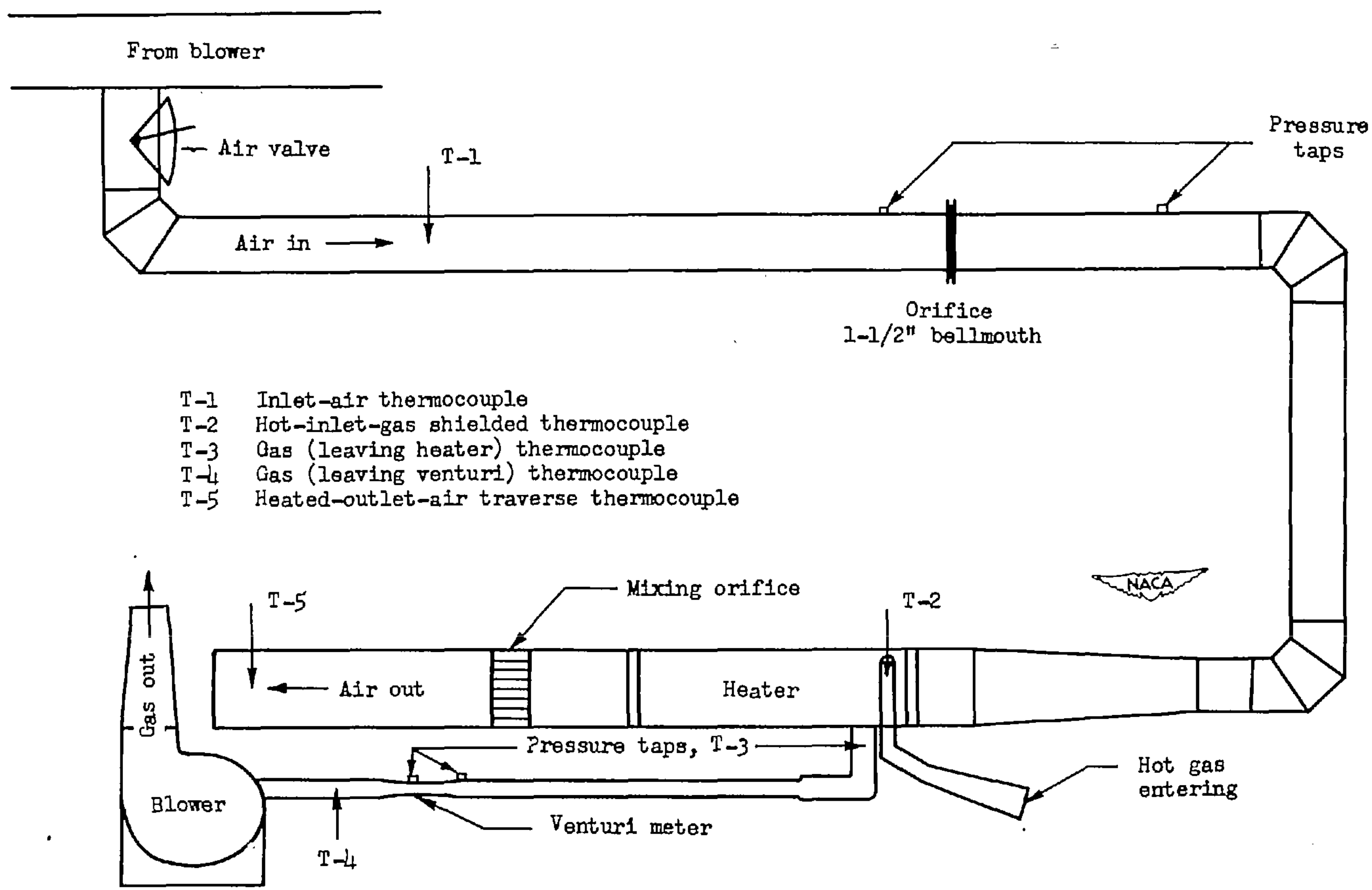
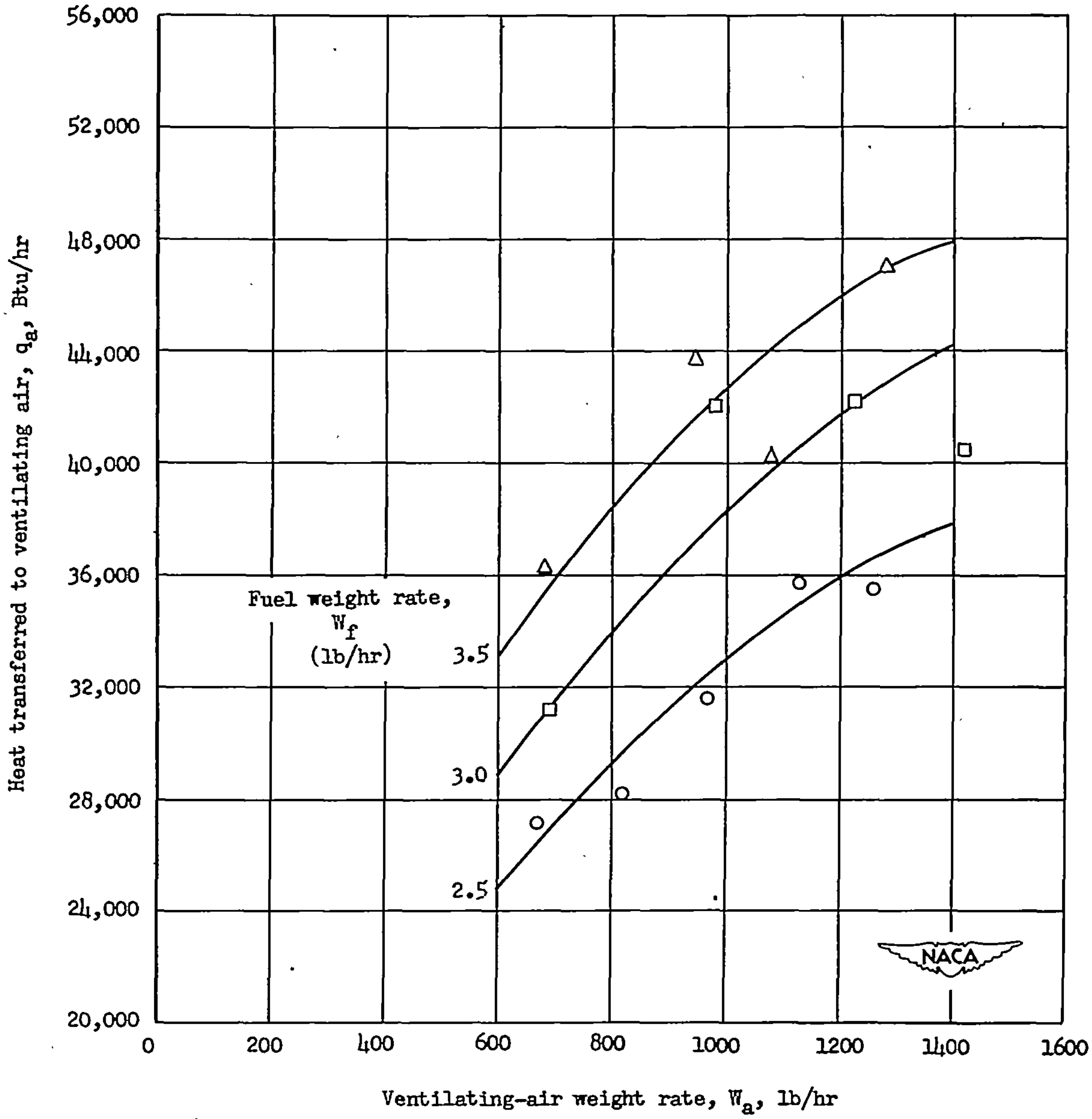
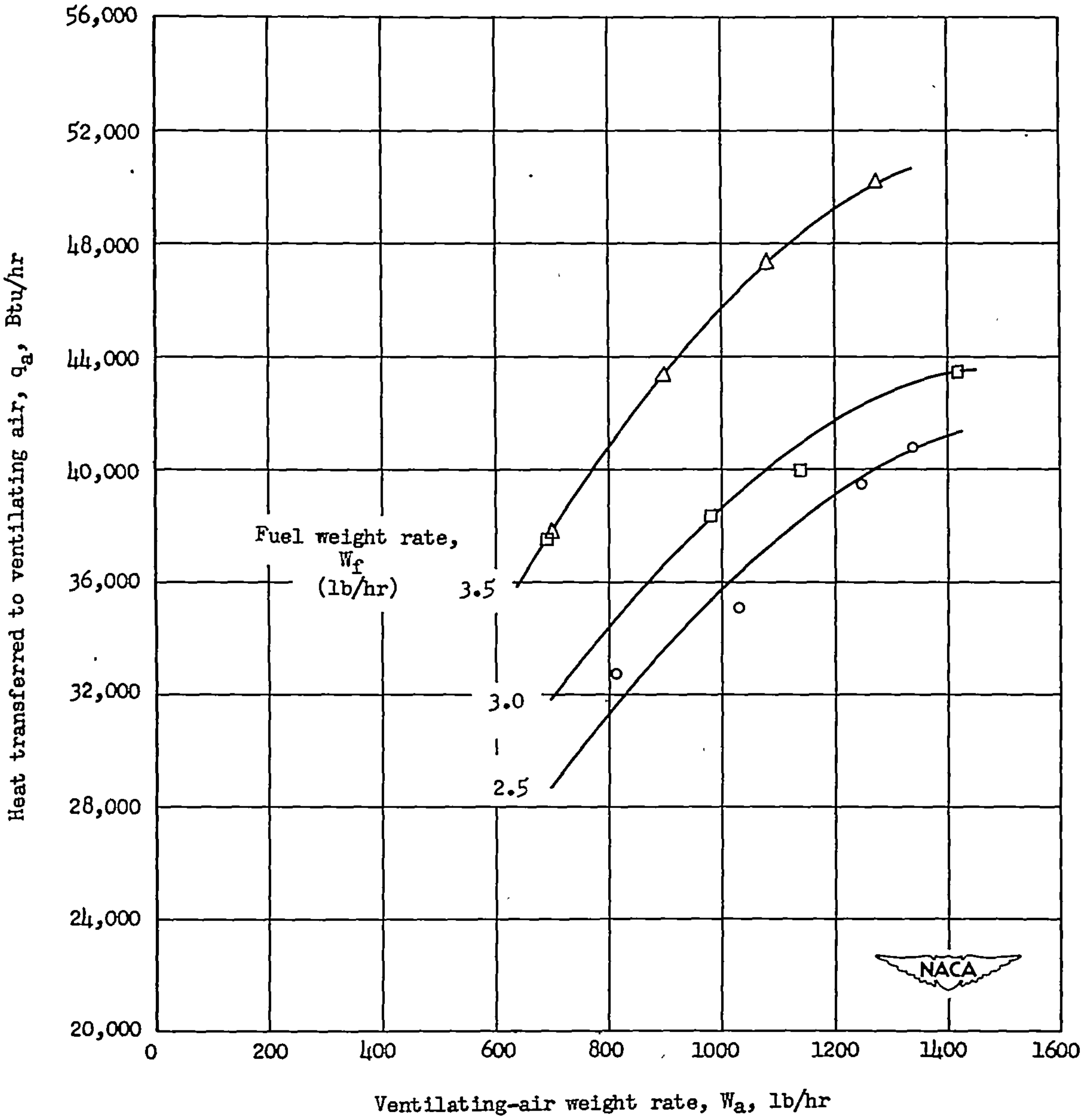



Figure 3.- Schematic diagram of heater test stand for preheated gases.



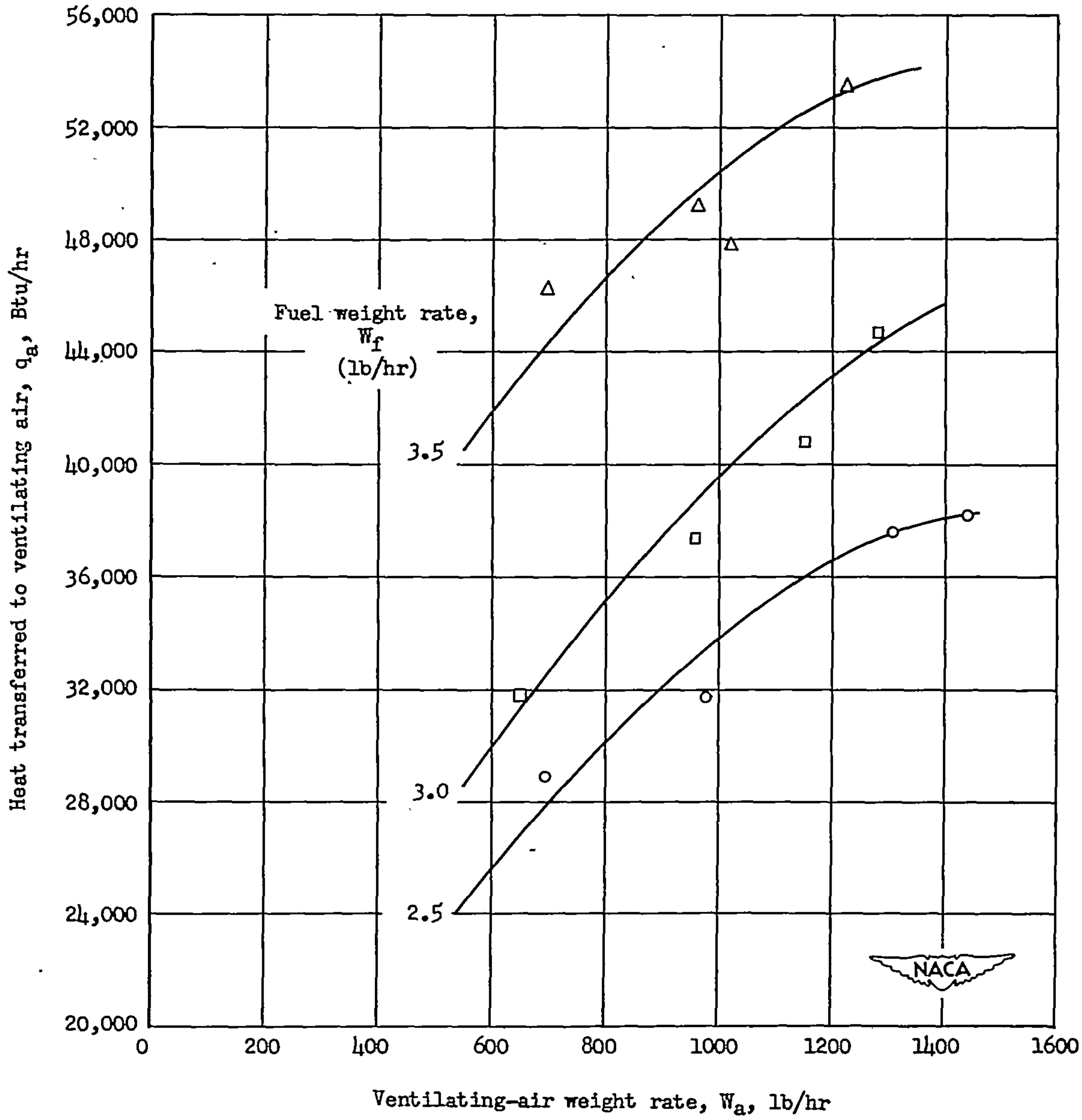

(a) Air-fuel ratio, 26.

Figure 4.- Variation of thermal output with ventilating-air weight rate.



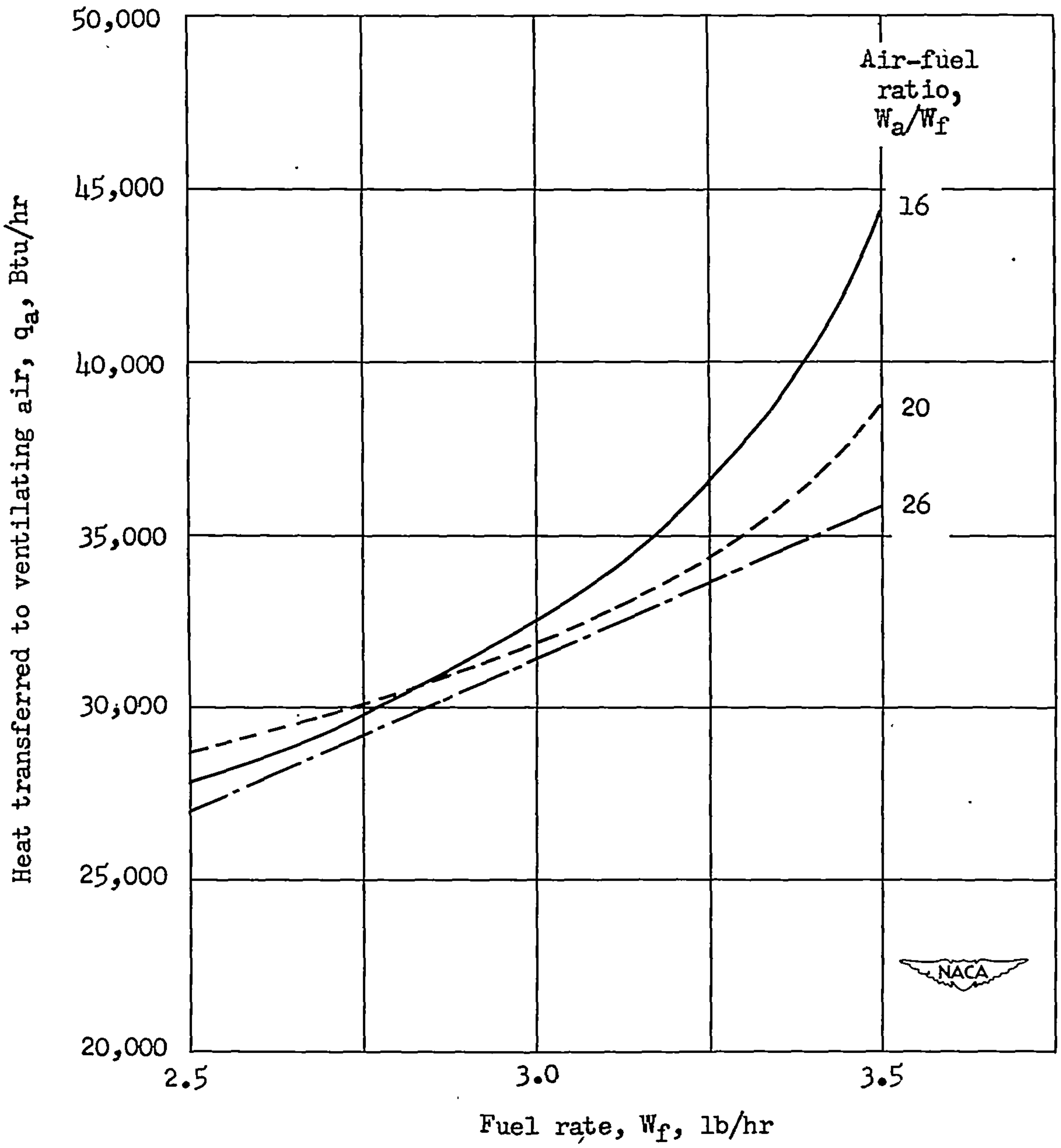

(b) Air-fuel ratio, 20.

Figure 4.- Continued.



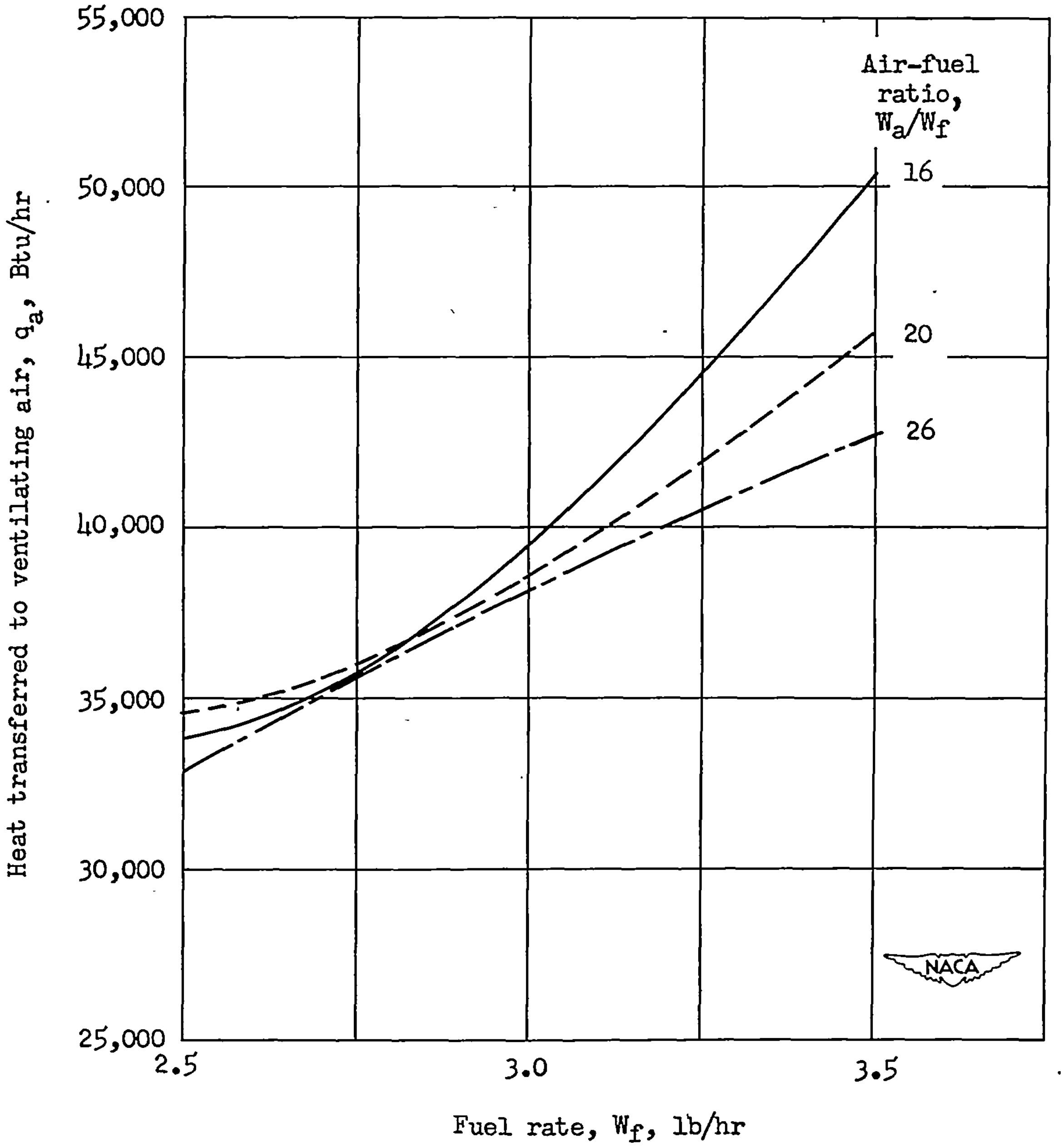

(c) Air-fuel ratio, 16.

Figure 4.- Concluded.



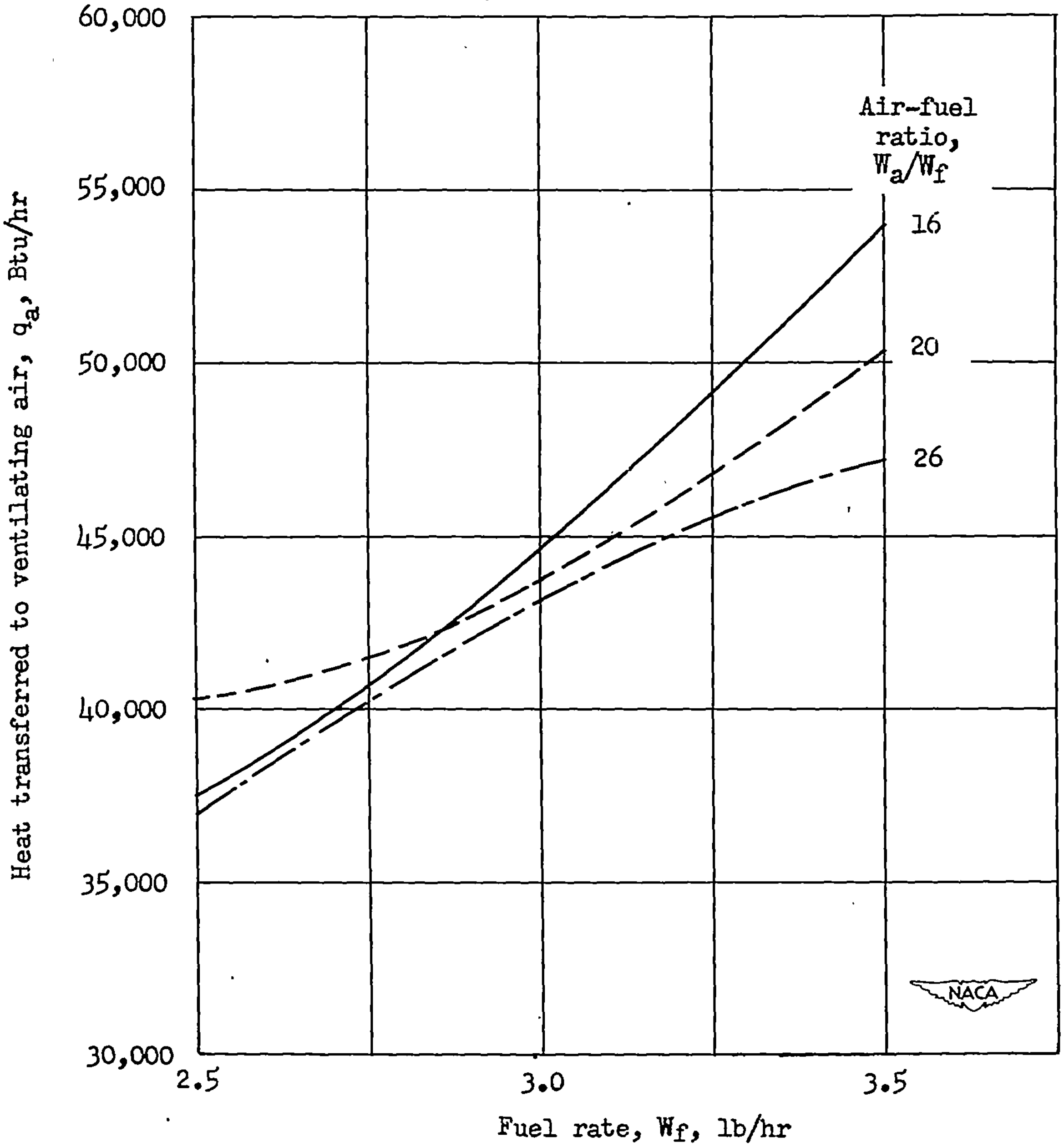

(a) Ventilating-air weight rate, 700 pounds per hour.

Figure 5.- Variation of thermal output with fuel weight rate.




(b) Ventilating-air weight rate, 1000 pounds per hour.

Figure 5.- Continued.




(c) Ventilating-air weight rate, 1300 pounds per hour.

Figure 5.- Concluded.

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